

CLAIMS

1. A method for determining temperature of a device which exhibits an exponential relationship between temperature and a voltage in response to an excitation current, comprising the acts of:
 - 5 sequentially applying at least three excitation currents of different values to the device along a current path in a predetermined current sequence for sequentially exciting the device for developing successive voltage values across the device in response to the excitation currents;
 - 10 sensing successive voltages developed across two sensing nodes in the current path on opposite sides of the device in response to the excitation currents; and
 - 15 combining the differences of the successive sensed voltages for determining a voltage indicative of the temperature of the device;
 - 20 wherein,
 - 15 the predetermined current sequence is selected so that as the differences of the successive sensed voltages developed across the two sensing nodes in the current path are being combined, the cumulative effect, in the sensed voltages, of voltage components resulting from series resistance in the current path between the two sensing nodes through the device is minimised, and
 - 25 the number of times the device is subjected to excitation by the excitation currents during the predetermined current sequence is selected so that the effect of the voltage components resulting from the series resistance in the current path between the two sensing nodes in the determined voltage indicative of the temperature of the device is substantially eliminated.
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 - 30 2. A method as claimed in Claim 1 in which the predetermined current sequence is selected so that each excitation current with which the device is excited is different to the excitation current with which the device had been previously excited.
 - 30 3. A method as claimed in Claim 1 in which the predetermined current sequence is selected so that each excitation current with which the device is excited is of value closest to the value of the excitation current with which the device had

been previously excited when the values of the currents in the predetermined sequence are being applied to the device in increasing order and decreasing order.

4. A method as claimed in Claim 1 in which the predetermined current sequence is selected so that the device is not sequentially excited by the excitation currents of highest and lowest values.
5. A method as claimed in Claim 1 in which the predetermined current sequence is selected so that the first excitation current of the predetermined current sequence is the excitation current which is closest to the average value of the excitation current of highest value and the excitation current of lowest value.
10. A method as claimed in Claim 1 in which the predetermined current sequence is selected so that the second excitation of the predetermined current sequence is the excitation current of highest value.
15. A method as claimed in Claim 1 in which the predetermined current sequence comprises excitation currents of three different values, namely, one excitation current of a high current value, one excitation current of a low current value, and one excitation current of an intermediate value, intermediate the high and the low current values.
20. A method as claimed in Claim 1 in which the differences of the successive sensed voltages developed across the two sensing nodes are combined during excitation of the device with the excitation currents in the predetermined current sequence, so that the determined voltage indicative of the temperature of the device is derived from the difference of at least one difference of the sensed voltages resulting from excitation of the device by two of the excitation currents, and at least one difference of the sensed voltages resulting from excitation of the device with 25 one of the said two excitation currents and another one of the at least three excitation currents.
30. A method as claimed in Claim 1 in which the differences of the successive sensed voltages developed across the two sensing nodes are combined during excitation of the device with the excitation currents in the predetermined current sequence, so that the determined voltage indicative of the temperature of the device is derived from the difference of at least one difference of the sensed voltages resulting from excitation of the device by two of the excitation currents, and at least one difference of the sensed voltages resulting from excitation of the device with one of the said two excitation currents and another one of the at least three excitation currents.

9. A method as claimed in Claim 8 in which the differences of the successive sensed voltages developed across the two sensing nodes are combined during excitation of the device with the excitation currents in the predetermined current sequence, so that the determined voltage indicative of the temperature of the device is derived from a plurality of differences of the sensed voltages resulting from excitation of the device by two of the excitation currents, and a plurality of differences of the sensed voltages resulting from excitation of the device with one of the said two excitation currents and another one of the at least three excitation currents.
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10. A method as claimed in Claim 1 in which the predetermined current sequence is selected so that the combined value of differences of the successive sensed voltages developed across the two sensing nodes resulting from excitation of the device by the currents in the predetermined current sequence initially progressively decreases to a minimum value, and then progressively increases.
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11. A method as claimed in Claim 1 in which the device is subjected to an even number of excitations by the excitation currents in the predetermined current sequence.
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12. A method as claimed in Claim 1 in which the device is subjected to the excitation currents for a plurality of the predetermined current sequences sequentially for compounding the voltage indicative of the temperature of the device determined during each predetermined current sequence in the next predetermined current sequence.
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13. A method as claimed in Claim 1 in which a Kelvin offset correction voltage is combined with the differences of the successive sensed voltages developed across the two sensing nodes, as the differences of the successive sensed voltages are being combined, for altering the voltage indicative of temperature of the device, so that a value of the voltage indicative of the temperature of the device of zero volts corresponds substantially to the lowest theoretical temperature of the
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temperature range within which the device is to be operational.

14. A method as claimed in Claim 13 in which the Kelvin offset correction voltage is provided as a coarse Kelvin correcting voltage and a fine Kelvin 5 correcting voltage.

15. A method as claimed in Claim 14 in which the values of the coarse and fine Kelvin correcting voltages are selected so that the coarse and fine Kelvin correcting voltages are combined with the voltage differences more than once as the device is 10 subjected to the excitation currents during the predetermined current sequence.

16. A method as claimed in Claim 15 in which the number of times the coarse and fine Kelvin correcting voltages are combined with the voltage differences as the device is subjected to the excitation currents during each predetermined current 15 sequence is less than the number of voltage difference combinations during each predetermined current sequence.

17. A method as claimed in Claim 1 in which the differences of the successive sensed voltages developed across the two sensing nodes resulting from excitation 20 of the device by the excitation currents in the predetermined current sequence are combined by integration.

18. A method as claimed in Claim 17 in which the integrating circuit in which the differences of the successive sensed voltages developed across the two sensing 25 nodes are integrated is a switched capacitor integrating circuit comprising a differential operational amplifier, and an offset voltage of the operational amplifier is compensated for by chopping its input pair in phase with the integration of the differences of the successive sensed voltages developed across the two sensing nodes, as the differences are being integrated.

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19. A method as claimed in Claim 1 in which the device which exhibits an exponential relationship between temperature and voltage in response to an excitation current is a PN junction.

20. A method as claimed in Claim 19 in which the PN junction is formed by a bipolar transistor having a current gain which is substantially constant within its operating range of collector currents.

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21. A method as claimed in Claim 20 in which the PN junction is formed by the base/emitter junction of the bipolar transistor, and the excitation currents in the predetermined current sequence are applied to the emitter of the transistor for developing the successive voltage values as base/emitter voltages of the transistor.

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22. A method as claimed in Claim 20 in which the bipolar transistor is a substrate bipolar transistor.

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23. A method as claimed in Claim 20 in which the bipolar transistor is diode connected.

24. A method as claimed in Claim 20 in which the collector of the bipolar transistor is connected to a fixed voltage.

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25. A method as claimed in Claim 1 in which the successive voltage values developed across the device in response to the excitation currents being applied in the predetermined current sequence, are filtered by placing a resistive element of a filter in the current path in series with the device between the device and at least one of the sensing nodes.

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26. A method as claimed in Claim 1 in which the excitation currents of respective different values are derived from a plurality of identical current sources by selecting the appropriate number of current sources to provide the respective excitation currents.

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27. A method as claimed in Claim 22 in which the excitation currents of values less than the excitation current of highest value are derived from the current sources by selecting a different combination of current sources each time each one

of the excitation currents of values less than the excitation current of highest value is to be derived.

28. A measuring circuit for determining temperature of a device which exhibits
5 an exponential relationship between temperature and voltage in response to an
excitation current, the circuit comprising:
- a current supply circuit for supplying at least three excitation currents of different values for exciting the device,
 - 10 a first switch circuit for selectively and sequentially applying the excitation currents to the device along a current path for sequentially exciting the device for developing successive voltage values across the device in response to the excitation currents,
 - 15 an integrating circuit coupled to two sensing nodes in the current path on opposite sides of the device for sensing successive voltages developed across the sensing nodes in response to the excitation currents, and for combining the differences of the successive sensed voltages for determining a voltage indicative of the temperature of the device,
 - 20 a control circuit for controlling the first switch circuit for applying the excitation currents to the device in a predetermined current sequence so that the successive sensed voltages developed across the two sensing nodes in response to the excitation currents in the predetermined current sequence is such that as the differences of the successive sensed voltages are being combined in the integrating circuit, the cumulative effect, in the sensed voltages, of voltage components resulting from series resistance in the current path between the two sensing nodes through the device is minimised, and
 - 25 controlling the number of times the excitation currents are applied to the device in the predetermined current sequence so that the effect of the voltage components resulting from the series resistance in the current path between the two sensing nodes in the determined voltage indicative of the temperature of the device is substantially eliminated.

29. A measuring circuit as claimed in Claim 28 in which the control circuit
controls the first switch circuit for applying the excitation currents to the device in
the predetermined current sequence so that each excitation current with which the
5 device is excited is different to the excitation current with which the device had
been previously excited.
30. A measuring circuit as claimed in Claim 28 in which the control circuit
controls the first switch circuit for applying the excitation currents to the device in
10 the predetermined current sequence so that each excitation current with which the
device is excited is of value closest to the value of the excitation current with which
the device had been previously excited when the values of the currents in the
predetermined sequence are being applied to the device in increasing order and
decreasing order.
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31. A measuring circuit as claimed in Claim 28 in which the control circuit
controls the first switch circuit for applying the excitation currents to the device in
the predetermined current sequence, so that the device is not sequentially excited
by the excitation currents of highest and lowest values.
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32. A measuring circuit as claimed in Claim 28 in which the control circuit
controls the first switch circuit for applying the excitation currents to the device in
the predetermined current sequence so that the excitation current with which the
device is first excited in the predetermined current sequence is the excitation
25 current which is closest to the average value of the excitation current of highest
value and the excitation current of lowest value.
33. A measuring circuit as claimed in Claim 28 in which the control circuit
controls the first switch circuit for applying the excitation currents to the device in
30 the predetermined current sequence so that the second excitation of the device is
with the excitation current of highest value.

34. A measuring circuit as claimed in Claim 28 in which the current supply circuit provides excitation currents of three different values for exciting the device in the predetermined current sequence, one of the excitation currents being of a
5 high current value, one of the excitation currents being of a low current value, and one of the excitation currents being of an intermediate value, intermediate the high and the low current values.
35. A measuring circuit as claimed in Claim 28 in which the integrating circuit
10 combines the differences of the successive sensed voltages developed across the two sensing nodes during excitation of the device with the excitation currents in the predetermined current sequence so that the determined voltage indicative of the temperature of the device is derived from the difference of at least one difference of the sensed voltages resulting from excitation of the device by two of the excitation
15 currents, and at least one difference of the sensed voltages resulting from excitation of the device with one of the said two excitation currents and another of the at least three excitation currents.
36. A measuring circuit as claimed in Claim 35 in which the integrating circuit
20 combines the differences of the successive sensed voltages developed across the two sensing nodes during excitation of the device with the excitation currents in the predetermined current sequence so that the determined voltage indicative of the temperature of the device is derived from a plurality of differences of the sensed voltages resulting from excitation of the device by two of the excitation currents,
25 and a plurality of differences of the sensed voltages resulting from excitation of the device with one of the said two excitation currents and another of the at least three excitation currents.
37. A measuring circuit as claimed in Claim 28 in which the control circuit
30 controls the first switch circuit for applying the excitation currents to the device in the predetermined current sequence so that the device is excited an even number of times.

38. A measuring circuit as claimed in Claim 28 in which the control circuit controls the first switch circuit for applying the excitation currents to the device in the predetermined current sequence for a plurality of predetermined current sequences sequentially, and the integrating circuit combines the differences of the successive sensed voltages during excitation of the device with the excitation currents in the plurality of sequential predetermined current sequences for compounding the voltage indicative of the temperature of the device determined during each predetermined current sequence in the next predetermined current sequence.

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39. A measuring circuit as claimed in Claim 28 in which the integrating circuit combines a Kelvin offset correction voltage with the differences of the sensed voltages developed across the two sensing nodes for altering the voltage indicative of temperature of the device, so that a value of the voltage indicative of the temperature of the device of zero volts corresponds substantially to the lowest theoretical temperature of the temperature range within which the device is to be operational.

40. A measuring circuit as claimed in Claim 28 in which the integrating circuit comprises a switched capacitor integrating circuit.

41. A measuring circuit as claimed in Claim 40 in which the switched capacitor integrating circuit comprises a differential operational amplifier, and a pair of input capacitors, one of which is coupled to one of the sensing nodes, and the other of which is coupled to the other of the sensing nodes, the input capacitors being successively charged by the successive sensed voltages on the respective sensing nodes, a second switch circuit being provided for selectively applying the charges on the input capacitors to respective non-inverting and inverting inputs of the operational amplifier, the second switch circuit being operated under the control of the control circuit for applying the charges on the respective input capacitors to the non-inverting and inverting inputs of the operational amplifier for integration of the differences of successive charges on the respective input capacitors resulting from the excitation currents being applied to the device in the predetermined current

sequence so that a differential voltage outputted by the operational amplifier after integration of the differences of the successive charges on the respective input capacitors, resulting from excitation of the device by the excitation currents in the predetermined current sequence is the voltage indicative of the temperature of the device.

42. A measuring circuit as claimed in Claim 41 in which the second switch circuit is operated under the control of the control circuit so that the successive charges on the respective input capacitors are alternately switched to the non-inverting and inverting inputs of the operational amplifier.

43. A measuring circuit as claimed in Claim 41 in which the signals on the non-inverting and inverting inputs of the operational amplifier are chopped in phase with the integration of the differences of the successive charges on the respective input capacitors for eliminating the effect of an offset voltage of the operational amplifier on the output voltage indicative of temperature of the device.

44. A measuring circuit as claimed in Claim 41 in which the first switch circuit is operated under the control of the control circuit for applying the excitation currents to the device in the predetermined current sequence, and the second switch circuit is operated under the control of the control circuit for integration of the differences in the successive charges on the respective input capacitors, so that the differential output voltage of the operational amplifier initially progressively decreases to a minimum value and then progressively increases.

45. A measuring circuit as claimed in Claim 41 in which a pair of Kelvin offset correction capacitors are provided for charging by respective corresponding coarse and fine Kelvin correcting voltages for altering the voltage indicative of temperature of the device, so that a value of the voltage indicative of the temperature of the device of zero volts corresponds substantially to the lowest theoretical temperature of the temperature range within which the device is to be operational.

46. A measuring circuit as claimed in Claim 41 in which a pair of feedback capacitors are coupled to the differential operational amplifier, one of the feedback capacitors coupling the positive output of the operational amplifier with the non-inverting input thereof, and the other feedback capacitor coupling the negative output of the operational amplifier with the inverting input thereof.
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47. A measuring circuit as claimed in Claim 46 in which a third switch circuit is provided for selectively discharging the feedback capacitors and for coupling the feedback capacitors between the corresponding one of the negative and positive outputs of the operational amplifier and a common mode output thereof for auto-zeroing the integrating circuit.
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48. A measuring circuit as claimed in Claim 28 in which the current supply circuit comprises a plurality of identical current sources, and the first switch circuit is operated under the control of the control circuit for selecting the appropriate number of the current sources to provide the respective excitation currents.
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49. A measuring circuit as claimed in Claim 48 in which the first switch circuit is operated under the control of the control circuit for selecting a different combination of current sources each time each one of the excitation currents of values less than the excitation current of highest value is to be selected within the predetermined current sequence.
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50. A measuring circuit as claimed in Claim 28 in which a filter is provided for filtering the successive voltage values developed across the device in response to the excitation currents being applied to the device in the predetermined sequence, the filter comprising at least one resistive element located in the current path between the device and at least one of the sensing nodes.
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- 30 51. A measuring circuit as claimed in Claim 50 in which the filter comprises a pair of resistive elements located in the current path on respective opposite sides of the device between the device and the respective sensing nodes.

52. A measuring circuit as claimed in Claim 50 in which the filter is an RC filter, and a capacitive element is provided for coupling the current path on one side of the device extending between the device and one of the sensing nodes, with the current path on the other side of the device extending between the device and the other of the sensing nodes.
53. A measuring circuit as claimed in Claim 28 in which the circuit comprises the device which exhibits an exponential relationship between temperature and voltage in response to an excitation current.
- 10 54. A measuring circuit as claimed in Claim 28 in which the device which exhibits an exponential relationship between temperature and voltage in response to an excitation current is a PN junction.
- 15 55. A measuring circuit as claimed in Claim 54 in which the PN junction is formed by a bipolar transistor having a current gain which is substantially constant within its operating range of collector currents.
56. A measuring circuit as claimed in Claim 55 in which the PN junction is formed by the base/emitter junction of the bipolar transistor, and the excitation currents in the predetermined current sequence are applied to the emitter of the transistor for developing the successive voltage values as base/emitter voltages of the transistor.
- 20 25 57. A measuring circuit as claimed in Claim 55 in which the bipolar transistor is a substrate bipolar transistor.
58. A measuring circuit as claimed in Claim 55 in which the bipolar transistor is diode connected.
- 30 59. A measuring circuit as claimed in Claim 55 in which the collector of the bipolar transistor is connected to a fixed voltage.